Nonclassical photon pairs from a cold atomic ensemble for scalable quantum communication

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Abstract: We report a dramatic improvement of the degree of nonclassical correlation between photon pairs generated by a cold atomic ensemble. The temporal dependence of this correlation and the influence of decoherence are described.

OCIS code: (270.0270) Quantum Optics

The development of long-haul quantum communication channels is one of the foremost challenges in quantum information science. In our view, one of the most promising scalable quantum communication schemes is the proposal by Duan, Lukin, Cirac, and Zoller (DLCZ) [1]. DLCZ is a probabilistic scheme based upon the entanglement of atomic ensembles via detection of single photons, where the sources of the photons are intrinsically indistinguishable. Generating nonclassically correlated photon pairs is a fundamental enabling step of implementing the DLCZ protocol. In our recent experiment [2], we cool cesium atoms in a magneto-optical trap (MOT) and drive them with two classical pulses, *write* followed by *read*, both resonant with cesium D_2 transitions. The nonclassical fields (1, 2) generated by the classical *write* and *read* pulse are then detected via photon counting electronics. The major limiting factor of our initial experiment [2] was the contamination of the correlated pairs (1, 2) by diverse uncorrelated backgrounds. Here we report substantial improvements for the generation of correlated photon pairs, and investigations of the underlying dynamics of the atom-field interaction.

To reduce the cross contamination, we employ Cesium D_2 transition ($6^2S_{1/2}$, F=4→$6^2P_{3/2}$, F=4) for the *write* beam and the D_1 transition ($6^2S_{1/2}$, F=3→$6^2P_{1/2}$, F=4) for the *read* beam. Leakage of photons from the classical pulses into the single photon detection channels is thus suppressed by 10^3, allowing the detection efficiency improvement. Optimization of the characteristics of the pulse durations and detunings for the *write* and *read* pulses decreased the number of uncorrelated photons further. We have thereby increased the observed degree of nonclassical correlation R between the (1, 2) fields by ~50 fold relative to that reported in [2]. Here, $R=g_{1,2}^2/(g_{1,1}\cdot g_{2,2})<1$ for "classical" fields (i.e., those with a positive Glauber-Sudarshan function), whereas we now measure $R>100$. $g_{i,j}$ are normalized correlation functions for single photons from the nonclassical (1, 2) fields, with $g_{i,j}=1$ for a Poisson process and (i, j)= 1 or 2.

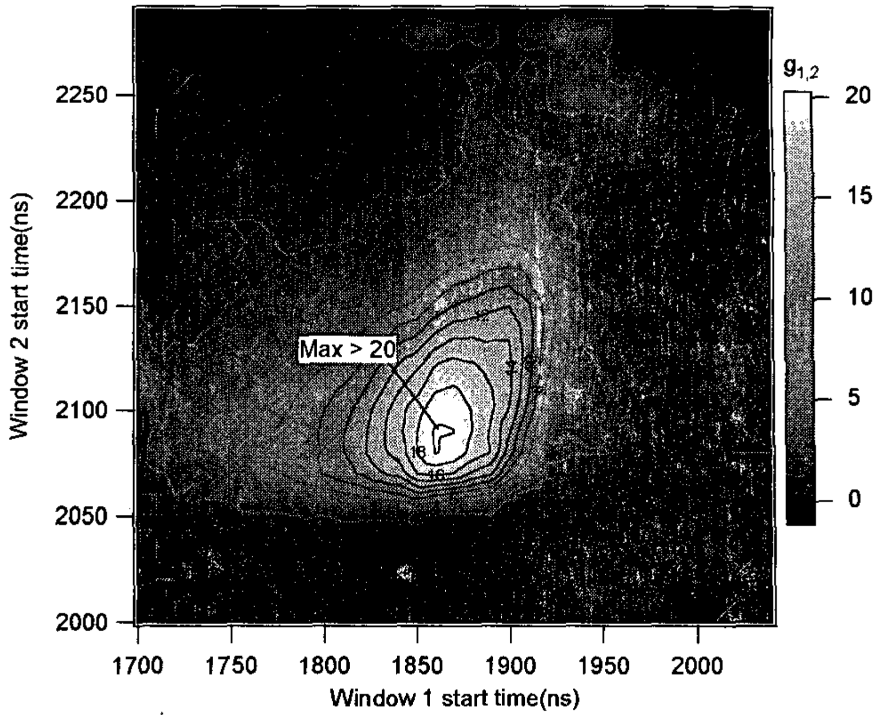

Fig. 1. Intensity correlation function $g_{1,2}$ versus the offsets of the gating windows for detection of the (1, 2) fields with respect to the beginning of each trial.

By recording the times of photoelectric detection events for the (1, 2) fields, we have also investigated the temporal dependence of the cross correlations as expressed by $g_{1,2}$, Figure 1. By shifting two 50 ns gating windows with respect to the driving pulses, we find that correlated pairs are distributed unevenly in time, yielding a sharp maximum for $g_{1,2}{\sim}20$.

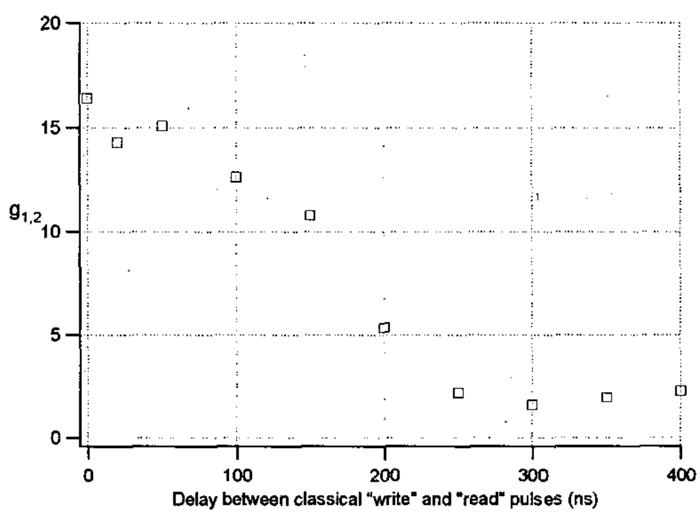

Fig.2. Decoherence in the MOT

We have also investigated the dependence of $g_{1,2}$ on the time delay τ between the classical *write* and *read* pulses. $g_{1,2}$ decreases with increasing τ, revealing the onset of decoherence between atoms in the ensemble for $\tau > 100$ ns, presumably due to Larmor precession in the quadrupole field of the MOT, Figure 2.

In conclusion, we report substantial advances in the degree of nonclassical correlation between photon pairs from a cold atomic ensemble in a MOT. We have examined the temporal structure of these quantum correlations and the decay of correlation with increasing delay between the classical driving pulses. Current research is directed toward the step-by-step implementation of the DLCZ protocol.

[1] Duan, L.-M., et. al, Nature **414**, 413–418 (2001)

[2] A. Kuzmich, et, al, Nature **423** 726-729 (2003)